Quid refert igitur, quantis jumenta fatiget
Porticibus ——

And both together, the uſe and deſtination of the building, which is the ſubject of our Inſcription, BASILICA (*i.e.* porticus) EQVESTRIS EXERCITATORIA.

As the Roman affairs in Britain are little known under this emperor; one only Inſcription beſides, as I obſerved, either bearing his name, or referring to his age, theſe notices may poſſibly be more welcome. And what makes the firſt Inſcription more ſo, is the mention of a new Legate, or lieutenant and pro-prætor, Valerianus, in this province, never taken notice of before. A copper Inſcription lately diſcovered in the eſtate of the D. of Norfolk in Yorkſhire, and now in his Grace's poſſeſſion, affords us another, and that a very remarkable perſonage, under the emperor Hadrian, and one much known in the Roman hiſtory.

What was the prænomen of this Legate, l. 9. is a matter of farther enquiry.

XXIX. *A Method of leſſening the Quantity of Friction in Engines, by* Keane Fitzgerald, *Eſq; F. R. S.*

Read May 12, 1763.

MECHANICS, or that branch of mathematics which conſiders motions and moving powers, their nature and laws, is properly diſtinguſhed into rational, and practical.

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A knowledge in rational mechanics, which comprehends the whole theory of motion, upon which natural philoſophy ſo greatly depends, is chiefly confined to the learned; and the proper conſtruction of engines and machines, which is the principal object of practical mechanics, altho' ſo very neceſſary to carry on the ſeveral branches of huſbandry, manufacture, and commerce, upon which, the riches and power of a nation depend in a great meaſure, is ſeldom attended to, but by the meer handicraftſman; who is little acquainted with the principles he works on, and from whom no great improvements can well be expected; yet it has happened ſometimes, that excellent contrivances have been invented, for raiſing heavy weights and overcoming their reſiſtances, by perſons who never took the trouble of examining into the cauſe of gravity.

As this branch is certainly moſt uſeful to mankind, and a knowledge in it, generally deemed one of the marks by which a civilized nation is diſtinguiſhed from barbarians, one would imagine, it ſhould have induced a greater attention to improvements in it, than has been generally found: But it often happens that mechanical powers, ſeemingly demonſtrable in theory, are found very deficient in operation, from unexpected obſtructions; which, with the expence and trouble that generally attend the reducing ſpeculations of this nature into practice, have probably been the greateſt obſtacles to improvements in it.

One of the greateſt obſtructions to the mechanical powers of engines proceeds from the friction, or reſiſtance of the parts rubbing on each other; which in general, is greater, or leſs, as the rubbing parts bear the greater, or leſs preſſure; and yet this obſtruction is but little attended to. The theoriſt makes no allowance on account of friction; and the practical mechanician, who feels the effects, yet, as if unavoidable, ſeldom takes the trouble of ſearching for a remedy.

Amongſt the few who have endeavoured to aſcertain the quantity of friction proceeding from weight, ſome have deemed it equal to $\frac{1}{3}$, others to $\frac{1}{2}$, and others more, or leſs, according to their different methods, or accuracy in making experiments. Doctor Deſaguillers gives an account of ſome experiments, which ſhew the quantity of friction in a cylinder, to be equal to $\frac{2}{3}$ of the power required to move it, when the ſurface of the cylinder moves as faſt as the power.

In order to examine the quantities of friction proceeding from different weights, I had an exact ballance made, which weighed 27 ounces; the pevets of the axis were $\frac{1}{2}$ inch diameter, and turned in braſs ſockets, fixed in a frame for the purpoſe.

Seven pound ſuſpended on each arm, at 18 inches diſtance from the center, required 1$\frac{1}{2}$ ounce, 2 penny weight, to be applied to either end, to overcome the reſiſtance from friction in the ſlighteſt degree; and 3 ounces to carry it down 2 inches.

Fourteen pound, applied in the ſame manner, required 3$\frac{1}{8}$ ounces to move the balance; and 6$\frac{1}{4}$ ounces to ſink either end 2 inches.

Twenty one pound required 4$\frac{1}{4}$ ounces to give it the leaſt motion, and 7$\frac{3}{4}$ ounces to ſink it about 2 inches.

Seven pound, ſuſpended on each arm at 9 inches diſtance from the center, required 3 ounces and $\frac{1}{4}$ to move either end in the leaſt degree.

Fourteen pound required 6⅜ ounces; and 21 pound required 9¼ ounces.

I placed another axis in the ſame ballance, the pevets of which were 1 inch diameter, and ſuſpended 7 pound on each arm at 18 inches diſtance from the center, which required 3¾ ounces to be applied to either end, to overcome the reſiſtance from friction; and then that end ſunk near 2 inches.

Fourteen pound, applied in the ſame manner, required 7½ ounces, which carried that end down ſomewhat more than 2 inches.

Twenty one pound required 11¾ ounces, and ſunk either end 2½ inches.

Seven pound, ſuſpended on each arm at nine inches diſtance from the center, required 7½ ounces to move either end.—Fourteen pound required 14 ounces, and 21 pound required 20½ ounces.

On repeating theſe experiments, there was little or no variation; and altho the ſeveral powers, required to overcome the reſiſtance from friction, do not correſpond exactly in proportion to the ſeveral weights and diſtances; yet it appears, that the leaſt power required, was equal to ½ the weight on the pevets; and that it required a power nearly equal to the whole weight, to overcome the reſiſtance from friction, with but a ſmall degree of velocity. But it does not follow, that the extraordinary power, ſeemingly required to overcome the friction with this degree of velocity, is to be attributed entirely to that cauſe, as part of it is neceſſary to raiſe the oppoſite weight with the ſame degree of velocity, tho' ſome part of it certainly is. For when there is little or no obſtruction from friction, a power a power of one ounce, more than what is juſt neceſſary to counterballance a weight of 7 pound, will raiſe it with as great a degree of velocity, as 2 ounces over and above what is juſt neceſſary to overcome the reſiſtance from friction. So that it muſt require an additional power in proportion, to overcome the reſiſtance from friction, with the ſame degree of velocity, that it may be neceſſary to raiſe the weight.

It is not imagined that theſe experiments ſhould determine the exact quantity of friction proceeding generally from weight, or preſſure; which probably can never be aſcertained by any experiments, however accurate; for even in engines of equal dimenſions, and loaded with equal weights, the quantities of friction may be very unequal, from circumſtances differing, which are ſometimes imperceptible; ſuch as the firmneſs, elaſticity, roundneſs and ſmoothneſs of the parts rubbing on each other; particularly the roundneſs, and ſmoothneſs of the gudgeons, or pevets, which, in large engines, are ſeldom turned true, or poliſhed. But it appears from theſe experiments, that the quantity of friction in large engines may reaſonably be eſtimated at $\frac{1}{2}$ the weight, or preſſure, on the rubbing parts; although in ſuch as are ſmall, and finiſhed with exactneſs, the quantity may probably be about $\frac{1}{3}$.

It is evident that the quantity of friction in any engine, is equal in its oppoſition to a certain portion of weight, or preſſure on the parts rubbing on a dead ſurface. And, altho' gravity is an active principle always tending to a center, and friction, a kind of vis inertiæ in oppoſition to motion, yet it may be conſidered mechanically as ſo much weight which requires a power to overcome its reſiſtance, in a ratio of the velocity of the power, to the velocity of the part rubbing on a dead ſurface; as in the axis in peritrochio, TAB. XII. Fig. 1. If the wheel A be 20 feet diameter, the axis B 1 foot diameter, the pevets *f* of the axis B 4 inches diameter, and the weight C to be raiſed by the axis B, 12 tons or 24,000 pounds

The power D, in the wheel A, with reſpect to the weight C to be raiſed on the axis B, is required in a ratio of the ſemidiameter of the wheel A to the ſemidiameter of the axis B, which is $\frac{20}{1}$; therefore the power D= 1200 pound is ſufficient to counterballance the weight C, and the leaſt additional power would raiſe it, if there were no obſtruction. But the quantity of friction in the pevets *f*, ſuppoſed equal to $\frac{1}{2}$ the weight or preſſure on that part, requires an additional power in the wheel A to overcome its reſiſtance, in a ratio of the ſemidiameter of the wheel A, to the ſemidiameter of the pevets *f*, or of the velocity of the power in the wheel A, to the velocity of the part rubbing on a dead ſurface in the pevets *f*, which are $\frac{60}{1}$. And as the weight of the wheel A, ſuppoſed 1500 pound, alſo the power D 1200 pound, required to counterballance the weight C 24,000 pound, in all 26,700 pound; center in the pevets *f*, the quantity of friction in the pevets *f*, being equal to $\frac{1}{2}$ the weight, or 13,350 pound hanging on them, will require a power in the wheel A ſomewhat more than 220 $\frac{5}{6}$ pound to overcome its reſiſtance. And as this additional power E 220 $\frac{5}{6}$ pounds cauſes an additional friction=110 $\frac{5}{12}$ pounds, it alſo requires a further power K = 1 $\frac{5}{6}$ pounds to overcome its reſiſtance; but the quantity of friction proceeding from thence, need not be eſtimated in a calculation of this nature.

Fig. 3.

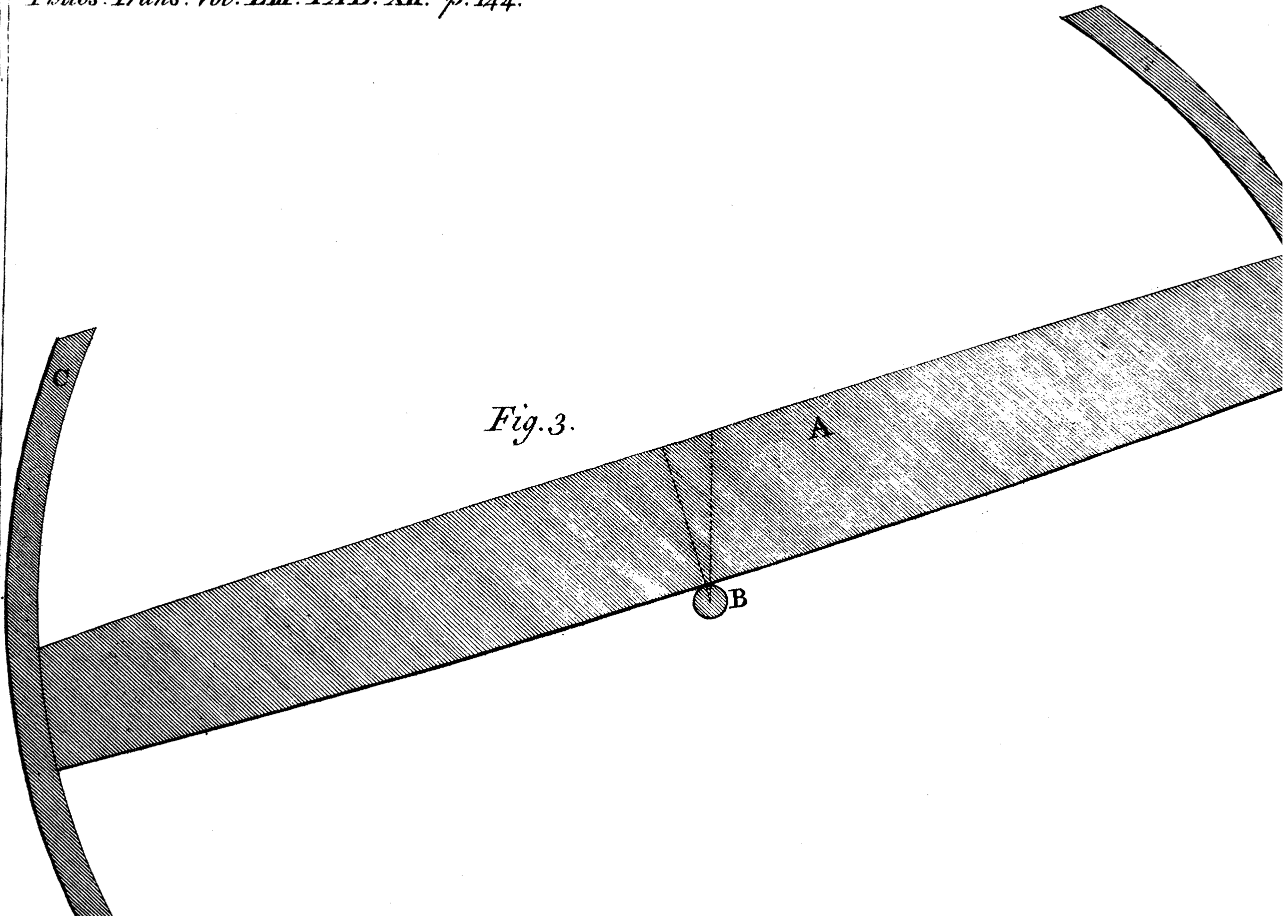


Fig. 4.

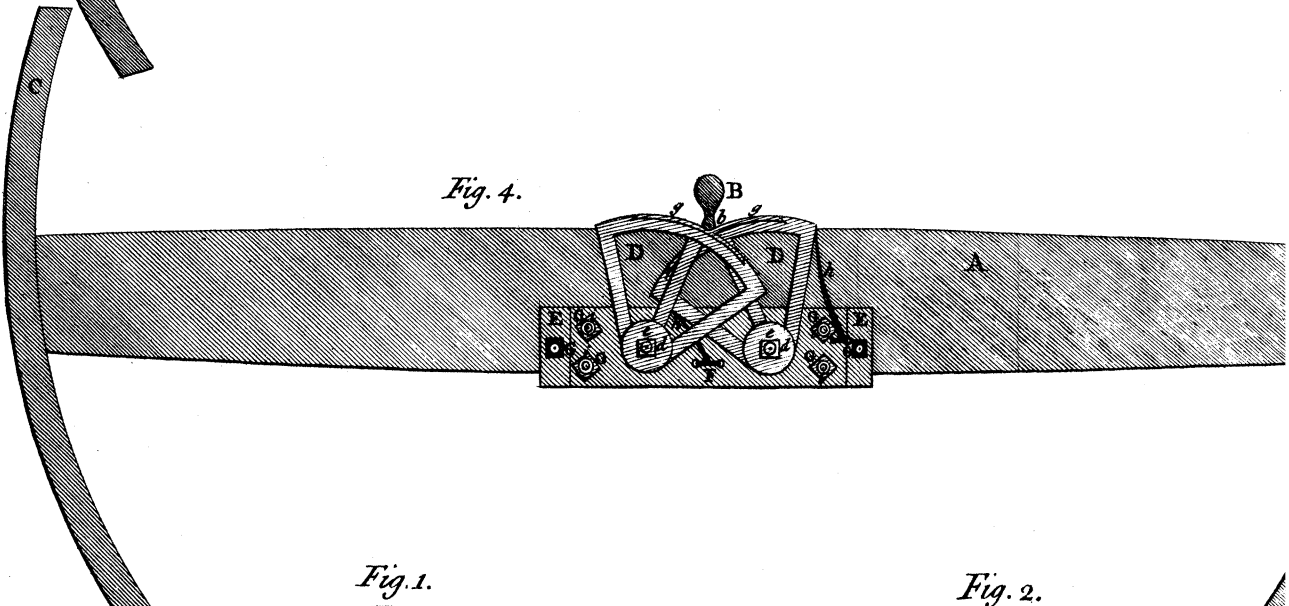


Fig. 1.

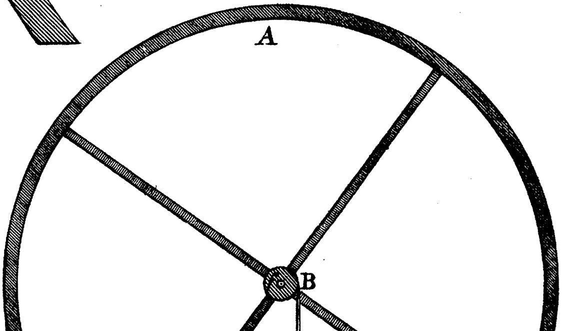
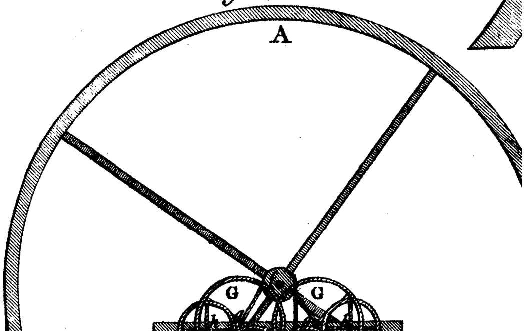
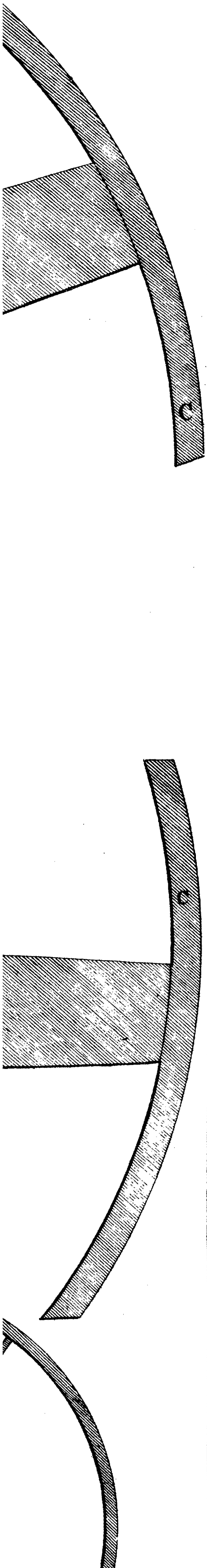


Fig. 2.

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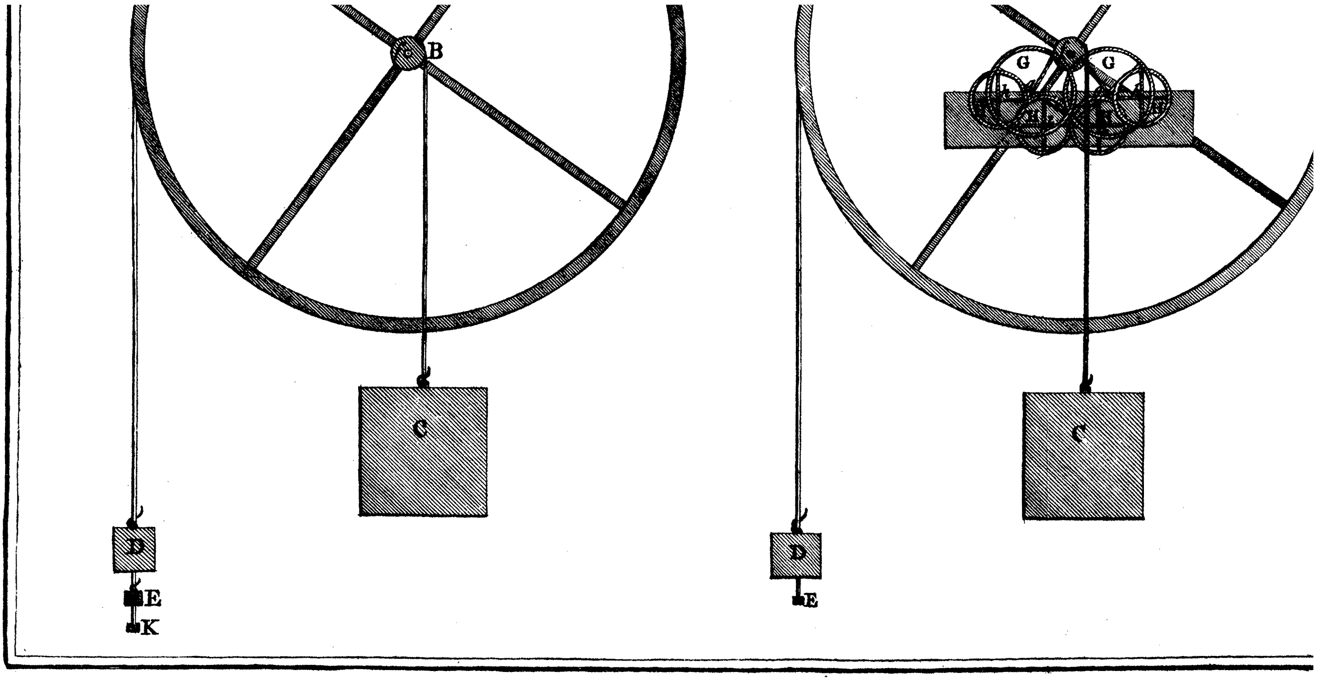
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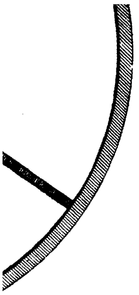

J. Mynde ſc.

As the power E, in the wheel A, with reſpect to friction in the pevets *f*, is in a ratio of the ſemidiameter of the wheel A to the ſemidiameter of the pevet *f*, it is evident, that, by enlarging the diameter of the wheel A, or reducing the diameter of the pevets *f*, the power over friction will be increaſed in proportion; but whatever power is gained by enlarging the diameter of the wheel A, will be loſt equally in time, or velocity, with reſpect to the weight C to be raiſed; and altho' there will be no loſs in time, or velocity, by reducing the diameter of the pevets *f*; yet this cannot be done beyond the proper degree of ſtrength required to ſuſtain the weight C &c.

As it alſo appears that the power E with reſpect to friction in the pevets *f*, is in a ratio of its velocity to the velocity of the pevet *f* rubbing on a dead ſurface, it follows, that if the velocity of the part rubbing on a dead ſurface can be decreaſed, whilſt the velocity of the power D continues in the ſame ratio, with reſpect to the weight C to be raiſed on the axis B; the power E over friction, will be increaſed in proportion, without any loſs in time or velocity, as to the weight C to be raiſed; which may be effected in the following manner, and the quantity of friction reduced to any degree that may be required.

Fig. 2. Let the pevets *f* of the wheel A, turn on the peripheries of the wheels G. G. 3 feet diameter, whoſe pevets *g*, *g*, are 1 inch diameter, and the whole friction will be transferred from the pevets *f*, to the pevets *g*, which will then be the only parts rubbing on a dead ſurface, by which means the velocity of the power in the wheel A, to the velocity of the pevets *g*, will be in a ratio of $\frac{2160}{1}$. For as the pevets *f*, 4

inches diameter, turn on the peripheries of the wheels G, 3 feet diameter, 9 revolutions of the pevets *f*, are equal to 1 revolution of the wheels G; and the circumference of the pevets *f*, being 4 times the circumference of the pevets *g*, the ſpace the pevets *f*, would have rubbed on a dead ſurface in one revolution, is equal to the ſpace the pevets *g* rub on a dead ſurface in 36 revolutions of the pevets *f*; therefore the velocity of the pevets *f*, being $\frac{36}{1}$ to velocity of the pevets *g*, and the velocity of the power D in the wheel A being $\frac{60}{1}$ to the velocity of the pevets *f*, the velocity of the power D, to the volocity of the pevets *g*, is $\frac{60}{1} \times \frac{36}{1} = \frac{2160}{1}$. So that $\frac{1}{2160}$ of 13250 pound, which was the weight equal to the quantity of friction in the pevets *f*; or a power ſomewhat more than 6 pound 2 ounces in the wheel A, will be ſufficient to overcome the reſiſtance from friction in the pevets *g*.

To reduce this quantity of friction to a leſs degree, let each of the pevets *g*, be placed on the peripheries of the wheels H, 2 feet diameter, whoſe pevets *h* are $\frac{1}{4}$ inch diameter; and the whole friction will then be transferred from the pevets *g*, to the pevets *h*; by which the velocity of the power in the wheel A, to the velocity of the part rubbing on a dead ſurface, in the pevets f, will be in a ratio of $\frac{207360}{1}$. For the circumference of the pevet g, being $\frac{1}{24}$ of the circumference of the wheel H, on which it turns, makes 24 revolutions, for 1 of the pevet *h*. And the circumference of the pevet *g*, being 4 times the circumference of the pevet *h*, the ſpace the pevet *g* would have rubbed on a dead ſurface in 1 revolution, is equal to the ſpace the pevet *h* rubs in 96 revolutions;

therefore the velocity of the pevet *g*, to the velocity of the pevet *h*, is $\frac{96}{1}$. And as it appears that the velocity of the power in the wheel A, is in a ratio of $\frac{2160}{1}$ to the velocity of the pevet *g*; conſequently its velocity to that of the pevet *h*, is $\frac{2160}{1} \times \frac{96}{1} = \frac{207360}{1}$. So that $\frac{1}{207360}$ of 13,250 pound the quantity of weight deemed equal to the friction originally in the pevets *f*, or a power E ſomewhat more than 2 ounces, will be ſufficient to overcome the friction in the pevets *h*.

Thus it is evident, that, by the application of additional wheels, or by enlarging the diameters of theſe, the reſiſtance from friction may be reduced to leſs than the reſiſtance of the medium the wheel paſſes through.

The whole weight which centers in the axis of the wheel A, being equally divided on the pevets *f*, and further ſubdivided on 32 pevets *h*, the weight on each of theſe pevets, being but $\frac{1}{16}$ of the weight on each of the pevets *f*, does not require more than $\frac{1}{16}$ of its ſtrength. And as the quantity of friction in each of the pevets *h* is in proportion to the weight or preſſure it bears, the ſum of the ſeveral quantities of friction in the 32 pevets *h*, is equal to the quantity of friction that was originally in the 2 pevets *f*, in proportion to their velocities.

There is alſo ſome additional friction in the pevets *h*, on account of the weight of the wheels G and H; but, with reſpect to the power in the wheel A, it is not of conſequence to require a calculation.

There is no engine for raiſing heavy weights, that has leſs friction than the axis in peritrochio. If the ſame weight were to be raiſed by 2 wheels, one multiplying the other; the power in the firſt wheel, being in a ratio of $\frac{5}{1}$ to the weight to be raiſed, and $\frac{10}{1}$ to the friction in its pevets; and the power of the ſecond wheel in a ratio of $\frac{4}{1}$ to the weight, and $\frac{6}{1}$ to the friction in its pevets; which powers are the ſame as in the wheel A, viz. $\frac{20}{1}$ with reſpect to the weight, and $\frac{60}{1}$ with reſpect to the friction; although the powers required to counterballance the weight on the axis, are equal in each; yet it would require a power above 733 pound to overcome the reſiſtance from friction in this engine, which is nearly treble the power required to overcome the friction in the wheel A, on account of four pevets rubbing on a dead ſurface in one, and but two pevets in the other.

By reducing the friction in the pevets of this engine, in the ſame manner as in the pevets of the wheel A, the power 733 pound, which is required meerly on account of friction, may be applied to raiſe an additional weight of 14,650 pound, without any diminution in point of time, or velocity, with reſpect to the weight to be raiſed; which at firſt view may ſeem contrary to the general principle, that whatever power is gained mechanically over weight, is loſt equally in point of time, and velocity; and is ſo in reality, with reſpect to practical mechaniſm; For the ſaving a power, otherwiſe, hitherto, found neceſſary to overcome the reſiſtance from friction, and applying it to the uſeful purpoſe of raiſing a greater quantity of weight, in equal time, is, in effect, equal to an acquiſition of ſo much power.

If theſe wheels are made with tolerable exactneſs, and placed, as in the drawing, on a line oppoſite to the point of preſſure of the pevets they ſupport, the preſſure will be equal on each wheel; and the greater the preſſure, the more ſecurely they are kept in their proper places. I have a double ſet of braſs wheels, 8 inches diameter, with which I have made ſeveral experiments, and find the practice anſwer as near as poſſible to the theory. But as the expence of braſs wheels, to large engines, would be very conſiderable, I had wheels made of wood, which I find to anſwer the purpoſe as well, if not better; as they are much lighter, and may be made ſtrong enough to ſupport a great weight, at a moderate expence.

The wooden wheels are fixed on an arbour, whoſe pevets have been turned true, and the edge of the wheel turned after it is fixed on the arbour. Theſe wheels are placed in a wooden frame, with a ſmall plate of braſs fixed properly in the frame, for the pevets to turn in. They may be made with ſpokes, and fellies, capable of ſuſtaining a conſiderable weight; and there is no danger of their wearing, as the pevet only rolls on the edge. I had wheels made of white deal, with ſeveral lamina glewed together, croſſing each other in different directions of the grain of the wood, which hinders them from warping, or cracking; and which I found, upon trial, anſwered extremely well. By croſſing the grain of the wood, the oppoſition to the preſſure on the periphery is pretty equal in all parts; and the edge of the wheel, in a little time, becomes as ſmooth, and almoſt as hard as braſs.

Theſe wheels cannot be applied to wheel carriages, unleſs they were to move on very even ground, as ſudden jerks, and turnings, would ſoon diſorder them. But they may certainly be employed to advantage in all fixed engines, that are loaded with heavy weights; eſpecially when the power that operates is expenſive, as men, horſes, fire, &c. And in finer kind of engines, where it may be neceſſary to avoid any obſtruction from friction as much as poſſible, the double, or treble wheels, where there is ſufficient room, will reduce the quantity to any degree that can well be required.

Another advantage alſo ariſes from the application of theſe kind of wheels, that, if the motion is required to be extremely ſwift, though the pevets be as ſmall as the weight they ſuſtain can allow of, yet they ſcarce ever wear the holes they turn in; for the laſt pevets in a treble ſet of wheels, which are the only ones that rub on a dead ſurface, will hardly make one revolution in two days.

There are ſeveral engines to which theſe wheels might be applied to advantage, even where the acting power coſts nothing; as watermills, where water is not always to be had plenty, which, by this means, would grind with much leſs water. Windmills, particularly, muſt receive great benefit from them; the ſhaft being ſo large, the quantity of friction, which is in proportion to the part rubbing on a dead ſurface, muſt be greater in this, than moſt other engines; beſides, the rubbing part being wood, muſt ſtill increaſe the quantity: I ſhould therefore imagine, that, if the ſhaft were placed on wheels 5, or 6 feet diameter, it would not require above half the ſtrength of wind, neceſſary at preſent. The frame in which theſe wheels might be placed, could eaſily be made in ſuch a manner, as to be lowered, or raiſed; ſo that if any inconvenience were found from too great velocity, when the wind increaſed, the ſhaft might then be let to turn in the uſual manner. But there would be no danger of the ſhaft taking fire by any degree of velocity, whilſt it turned on theſe wheels, as it would not then rub at all.

There have been many ingenious attempts, and ſome conſiderable improvements made, with reſpect to the ſaving of fuel neceſſary to work a fire engine, which is an article of great expence: but I do not find the diminution of friction has been conſidered as any ways material in this point, although it muſt neceſſarily reduce the quantity of fuel in proportion.

The power of a fire engine is eſtimated by the diameter of the cylinder and piſton; on which the atmoſphere preſſes, when there is a vacuum made by the condenſation of the ſteam with which the cylinder has been filled. This power, or preſſure, is deemed equal to 15 pound per inch ſquare on a medium: but I ſhould imagine, that the ſteam, with which the cylinder is filled, being water expanded into 4000 times it's bulk by the action of fire, when reduced to its original ſtate by a ſtrong injection of cold water daſhing againſt the bottom of the piſton, and mixing with it, muſt occupy ſuch a ſpace in the cylinder, as to hinder a perfect vacuum, which appears, in ſome meaſure, from the effects; for the power of the atmoſphere on a fire-engine is ſeldom found to raiſe 7 pound per inch, and it can hardly require 8 pound per inch to overcome the friction of the ſeveral parts of the engine, and alſo to give a proper degree of velocity to the leaver.

The friction of the piſton moving up and down in the cylinder, and of the forcers or working rods, is in proportion to the diameter of the cylinders they work in. That of the plug frame, which is a piece of timber moved by the leaver through a wooden groove, by which the ſteam valve, and injection cock are opened and ſhut alternately, is pretty conſiderable; but the quantity proceeding from the ſeveral parts cannot be eſtimated with any tolerable degree of preciſion.

The whole weight to be raiſed, as alſo the ſuperior power by which it is raiſed, center in the pevets of the axis of the great leaver, and the quantity of friction in the pevets, may be deemed equal to half ſo much weight hanging on them.

In order to form ſome eſtimate of the quantity of weight with which the axis of the leaver of a fire-engine is loaded, I took the dimenſions of the ſeveral parts of that at the York-Buildings water-works; the leaver of which is 27 feet long, 2 feet 6 inches by 2 feet 2 inches in the middle, and 2 feet by 22 inches at the ends. The weight of which, with the archeads, chain, rods, and working frame hanging at one end, and the piſton and chain at the other, may be computed at 6 tons, or 12,000 pound. The cylinder is 45 inches diameter, about 1591 ſquare inches; which, at 15 pound per inch preſſure of the atmoſphere, is 22,274 pound. The pillar of water to be raiſed is 10,060 pound, which is not 6 $\frac{1}{2}$ pound per inch; ſo that the remainder of the power is employed in overcoming the reſiſtance from friction in the ſeveral parts of the engine, and giving the leaver a degree of velocity equal to 120 feet per minute, which it moved in common work.

The weight of the power, or preſſure, of the atmoſphere taken at 14 pound per inch ſquare, 22,274 pound, with the pillar of water 10,060 pound, and alſo of the leaver, &c. 12,000 pound; amounting in the whole to about 22 tons, center in the axis of the leaver. The quantity of friction reſulting from this weight, ſuppoſed equal to half, or 11 tons, hanging on the pevets 6 inches diameter, the leaver being 27 feet long, requires a power at either end = 425 pound to overcome its reſiſtance in the leaſt degree, and muſt ſtill require a further power to overcome the friction of the other parts of the engine, and give the leaver a degree of velocity = 120 feet per minute.

Before I give an account of the method I took to reduce the quantity of friction in the pevets, it may be proper to mention a general error in the manner of placing the axis of the leaver under the beam. A ballance, having its center of motion underneath, and equal weights at each end, being placed horizontally, will remain in that poſition; as both weights are equidiſtant from the center of gravity, which is perpendicular to the center of motion; but when it is made to incline to either ſide, it will continue to move on that ſide, untill it becomes parallel to the horizon, with the center of motion above the ballance: for when either end is depreſſed in the leaſt degree, as in fig. 3, it becomes more diſtant from the center of gravity; and the oppoſite end which is raiſed in proportion, is brought nearer to it, although both ends ſtill continue equidiſtant from the center of motion.

Fig. 3. The lever A of this engine is 2 feet 9 inches from the upper part of the beam, to the center of it's axis B placed underneath; and weighs, with it's arch-heads, about 5 tons. When it was placed in a horizontal poſition, it required but 93$\frac{1}{2}$ pound to overcome the reſiſtance from friction in the pevets; but when either end was depreſſed 4 feet below the level, at which diſtance the ſprings are fixed, it required 534 pound to be applied to the oppoſite end to bring it back again: ſo that a power $=440\frac{1}{2}$ was required, on account of the center of gravity being ſo much changed by the poſition of the axis underneath.

Fig. 4. To avoid this general error, I had the axis B placed on the upper ſide of the leaver, and fixed by proper bolts and ſcrews to a bar of iron equally ſtrong, placed underneath: and, in order to reduce the quantity of friction, which is in proportion to the ſpace rubbing on a dead ſurface in equal time, I had them made in the form *b* B, fig. 4, by which they are equally ſtrong, though the rubbing part *b*, is but 1$\frac{1}{2}$ diameter; ſo that by changing only the form of the pevets, the friction is reduced to $\frac{1}{4}$ of it's original quantity. I applied two quadrants, D D, to each of theſe pevets, whoſe radii are 2 feet 6 inches, by which the whole friction of the pevets *b* of the axis of the leaver, are transferred to the pevets *d* of the quadrants, which are 1$\frac{1}{2}$ inch diameter. Theſe quadrants are equal in effect to wheels 5 feet diameter; the radius of which is $\frac{40}{1}$ to the ſemidiameter of its pevet, and reduce the friction in the pevets of the quadrants to $\frac{1}{40}$th part of what it was in the pevets *b* of the axis; which × by $\frac{4}{1}$ the reduction made by changing the form of the pevets $=\frac{160}{1}$: by which means the

friction that was in the pevets B, fig. 3. of the great axis, which was = 425 pound, is reduced to $\frac{1}{160}$, or ſomewhat leſs than 2$\frac{3}{4}$ pound.

Upon trial, the leaver, that before required a power of 95 pound to overcome the leaſt reſiſtance from friction, was as eaſily effected by the application of $\frac{3}{4}$ pound; and the reſiſtance from friction occaſioned by a weight of 6 tons is of ſo little conſequence, that the leaver may be ſwung with a ſlight thread, and will continue in a ſtate of vibration for ſeveral minutes after.

The original quantity of friction in the pevets B of the leaver A, fig. 3. which, when loaded with it's full weight 22 tons, required a power = 425 pound to overcome it's reſiſtance, is by this method reduced to 2 pound 10 ounces; and, if there were any need of reducing it further, it might be done by applying two ſmall quadrants to each pevet of the larger, which would reduce it to one ounce or leſs.

It is not eaſy to determine the quantity of friction that was in the plug frame, but that has alſo been reduced to $\frac{1}{16}$ by the application of ſeveral rollers 5 inches diameter, whoſe pevets are $\frac{1}{4}$ inch diameter, on which it now moves. But it is evident that a power = 440 $\frac{1}{2}$ has been ſaved by changing the poſition of the axis of the leaver; and a power of 421 pound 6 ounces by reducing the quantity of friction in the pevets.

The viſible effect, with reſpect to the working of the engine, according to the moſt exact obſervations by different perſons, both before, and after theſe ſeveral alterations were made, is, that it now makes 18 ſtrokes at 8 feet per ſtroke, for 15 that it ever made, with the ſame, or rather a ſmaller quantity of fuel; and muſt therefore diſcharge $\frac{1}{6}$ more water in equal time; which conſequently ſaves $\frac{1}{6}$ of the fuel. But the effect is found ſtill greater, as to ſupplying the tenants with water; for the engine performs the ſame ſervice better now in 5 hours, than ever it did before in ſix: which can only be accounted for, by the extraordinary regularity of its ſtroke, which does not abate of it's full length ſuddenly, as it uſed to do, when the ſtrength of the fire abated: this I take to be occaſioned in a great meaſure, from placing the axis above the leaver, by which the center of gravity becomes reverſed to what it was before; ſo that it requires the ſame power to keep the end of the leaver depreſſed as low as the ſprings, that it required before to bring it back, when ſo much depreſſed; which is a particular benefit; for the ſtop, or ſett, generally in large engines, when the ends of the leaver come to the ſprings, is a defect that has been endeavoured to be remedied in ſome degree, by the help of the ſprings. But when the axis is placed above the leaver, and the friction reduced, as in fig. 4, if one end is brought down to the ſprings, and let to return, it carries the other end down to the ſprings without any aſſiſtance, and will continue to do ſo ſeveral times, abating ſomewhat of the length of the ſtroke, each time.

This engine, from ſeveral improvements that have been made in the boyler, conſumes but 4 buſhels of coals in an hour; which is deemed $\frac{1}{3}$ leſs than others of equal bigneſs; and it performs the ſame work now in 20 hours, that it did before in 24 hours, it is a ſaving, in effect, of 16 buſhels in 24 hours, amounting to 162 chaldrons in a year's conſtant work; which is a very conſiderable article, even where coals are to be had at a cheap price.

It may be proper to obſerve that the archeads C of the leaver, muſt be drawn from the center of the ſmall part *b* of the pevet, which turns on the quadrants. The quadrants and frame muſt be made ſufficiently ſtrong, which I had made of caſt iron. The pevets of the quadrants are made of tempered ſteel, and turned true. There are four pillars G in the back plate of the frame, with ſhoulders, and ſtrong ſcrews, which paſs through the fore plate, and are ſcrewed tight by a nut *i*, when the quadrants are placed in the frame.

The back plate E (fig. 4.) of the frame, is longer than the fore plate F, in order to admit the iron bolts G at each end; by which the frame is ſcrewed to a wooden block. The edges of the frame reſt on a broad plate of iron, laid on a level board; upon which the blocks and frames are placed, and bolted down in the uſual manner. The holes that the pevets of the quadrants turn in, are made in ſquare pieces of braſs *e*, riveted for the purpoſe into the frame plates.

The round part *b*, of the axis B, fig. 4, is made of hardened ſteel, and the edges *g* of the quadrants are alſo of the ſame metal; otherwiſe the very great weight they ſuſtain, would make a deep impreſſion in that part. There are two ſprings, *h h*, to each quadrant, which keep them in their proper places, and yield eaſily to the motion of the quadrants.

There was great care taken to make the frame ſquare, and place the quadrants upright and level;

and alſo to place the leaver exactly in the center. By which means there has been no alteration required ſince they were firſt fixed; and the engine continues to work as even, and true as it is poſſible.

I have applied wheels for reducing friction to ſome other engines with great advantage, which I ſhall take the liberty of laying before the Royal Society ſome other time; and fear I have treſpaſſed too much on their patience already by this long detail.

XXIX. *The Difference of Longitude between the Royal Obſervatories of* Greenwich *and* Paris, *determined by the Obſervations of the Tranſits of* Mercury *over the* Sun *in the Years* 1723, 1736, 1743, *and* 1753: *By* James Short, *M. A. F.R.S.*

Read June 2, 1763.

IT will, no doubt, appear ſurprizing, that I ſhould attempt to determine the difference of longitude between two of the moſt celebrated obſervatories in Europe; and in which ſome of the greateſt aſtronomers, that ever lived, have, for above eighty years, been conſtantly obſerving the motions of the heavenly bodies: yet it is moſt certain, that, to this day, we are ignorant of the ſaid difference of longitude: the Engliſh aſtronomers reckoning it to be = 9′ 20″, and the French ſetting it down at 9′ 10″, which, they tell us, was found

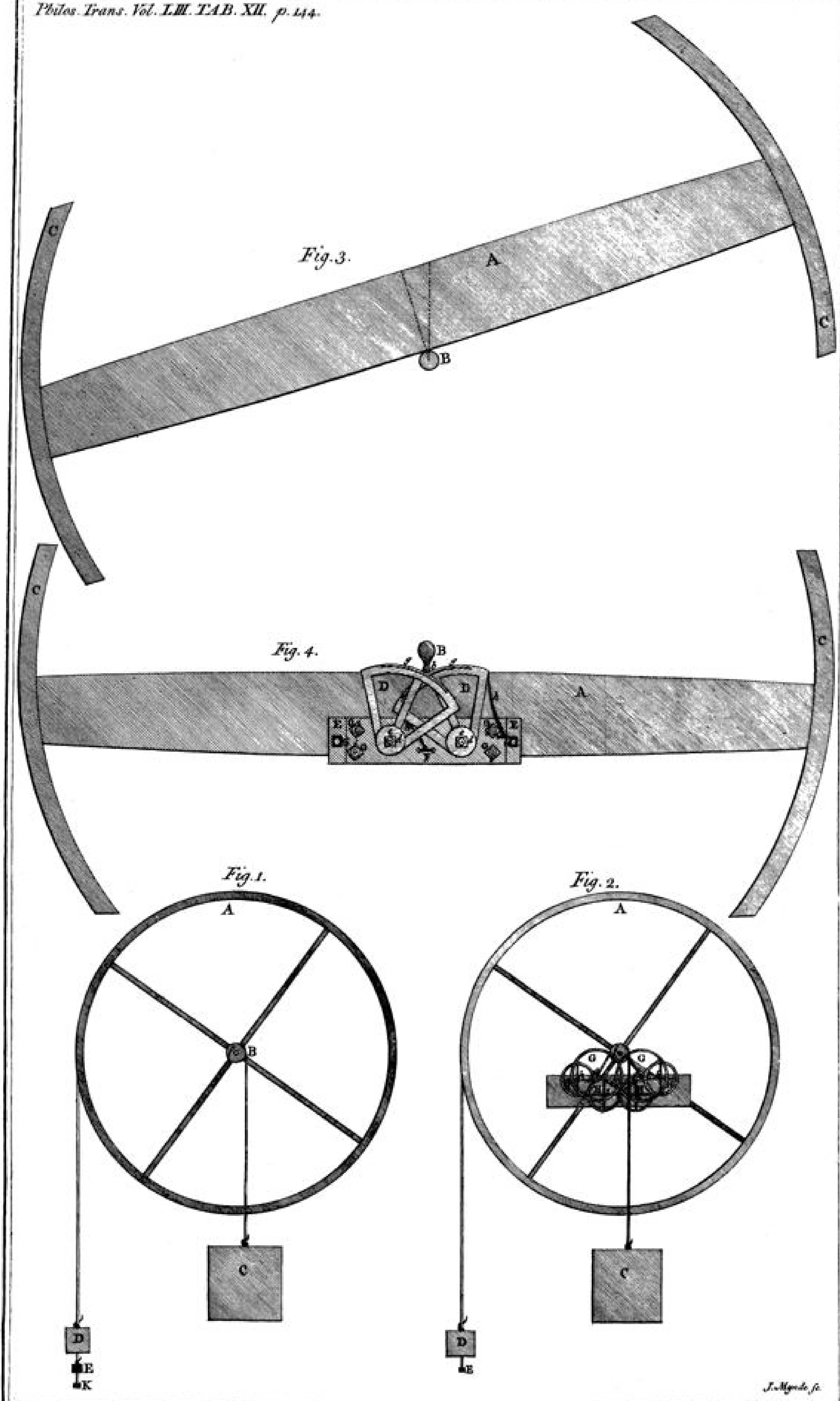

Fig. 3.

Fig. 4.

Fig. 1.

Fig. 2.

J. Mynde fc.